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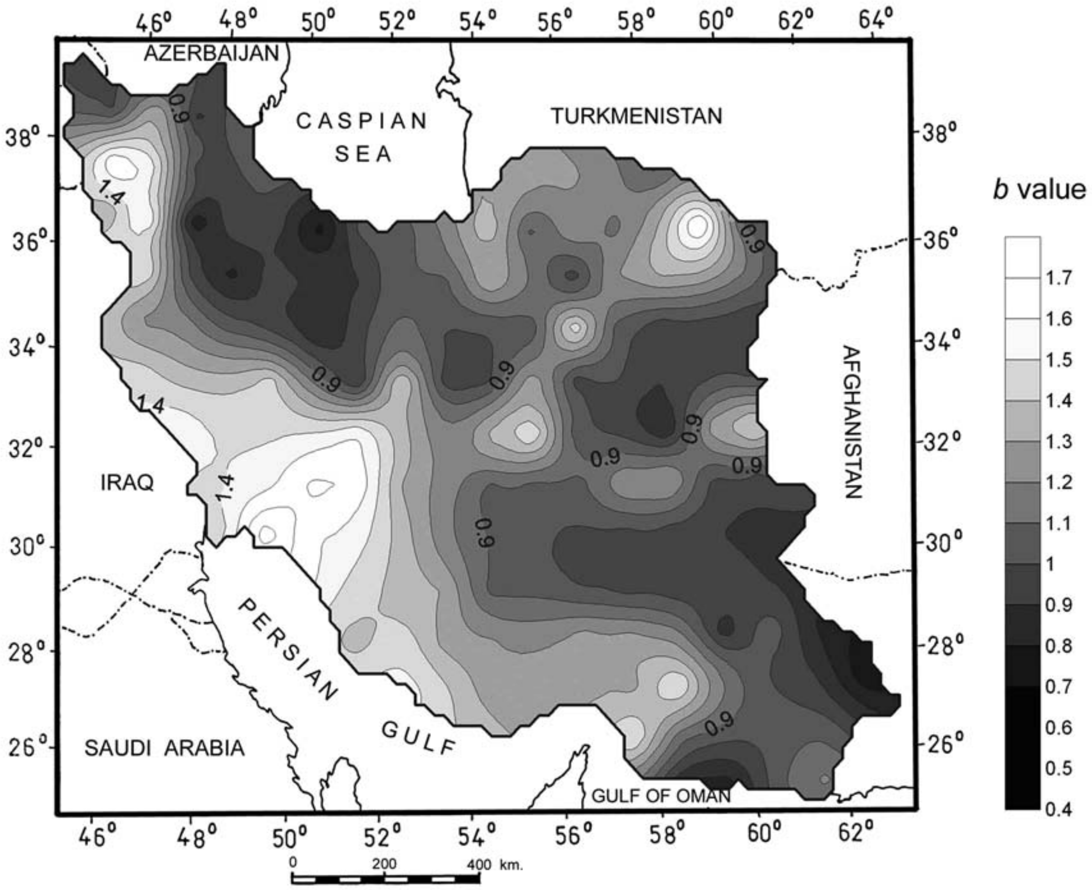

Fig. 6- Contour map showing the spatial variation of seismic *b*-value over Iran.

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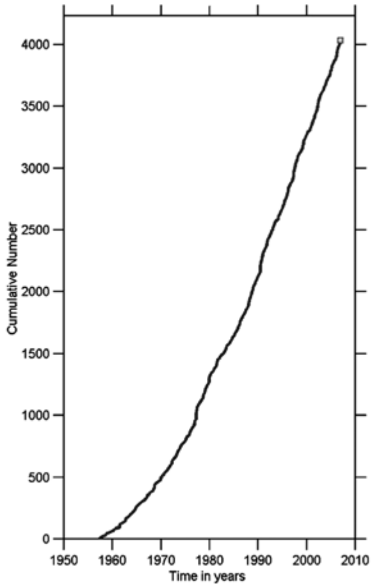

Fig. 2 -Graph showing the cumulative number of earthquakes with m_b 4.0 and greater versus time occurred in Iran.

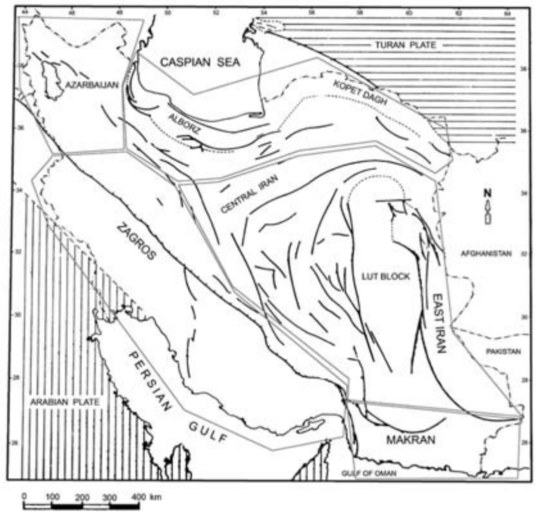

Fig. 3- General structural map of Iran showing the main structural zones and major active faults of the region (modified and adapted from Berberian, 1976). The approximate location of structural zones were shown as polygons.

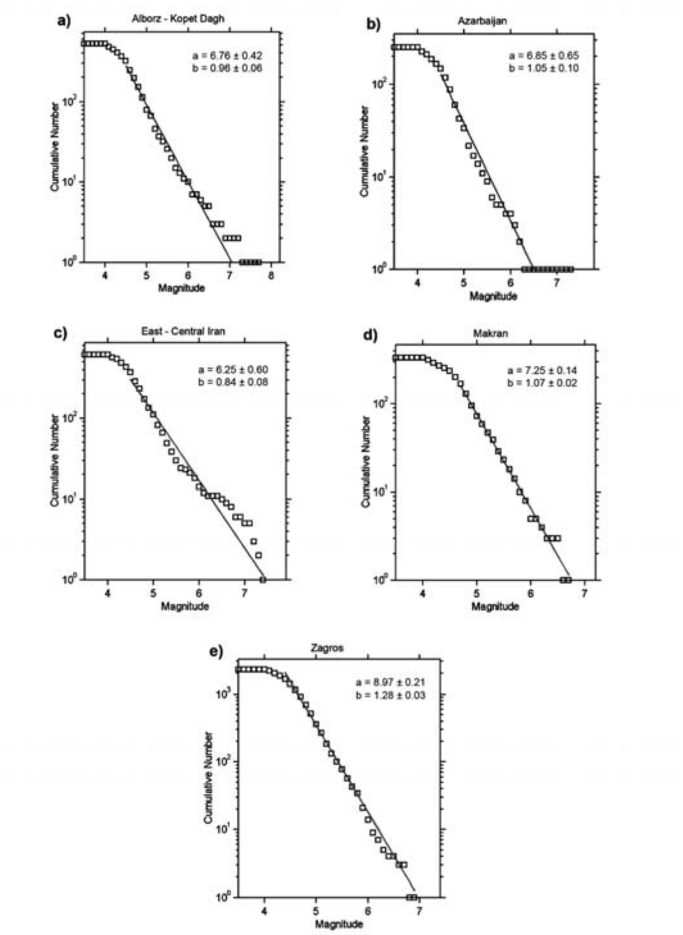

Fig. 4 - Diagrams showing the frequency-magnitude distribution of earthquakes for the five structural zones of the Iranian region (Fig. 3.); a) Alborz-Kopet Dagh zone, b) Azarbaijan zone, c) East-Central Iran zone, d) Makran zone, and e) Zagros zone.

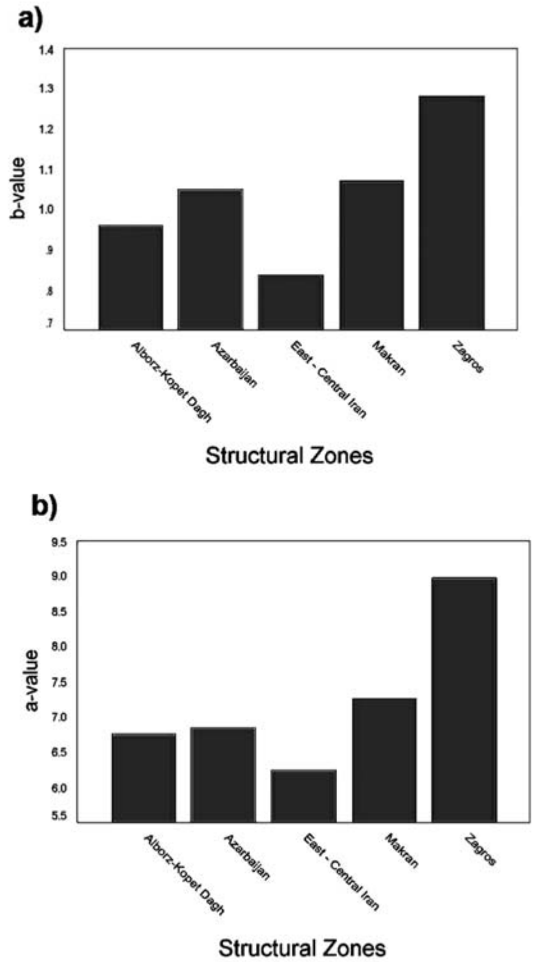

Fig. 5- Plots showing the values of seismic parameters calculated for the five structural zones of the study region; a) Gutenberg-Richter *b*-value, b) Gutenberg-Richter *a*-value.

to the location of major active faults that act as good places for releasing seismic strains. A comparison between the results of this research and the results obtained by Zamani and Asadi (1995) indicates that although the general pattern of *b*-value variation in both works are similar, but the map produced in this research shows better agreement with the structural and tectonic pattern of the region.

3. Conclusions

To study the spatial variation of *b*-value over the Iranian region, the seismic data of the region covering a time period of nearly 50 years from 1957 to 2007 have been analyzed. For this purpose, based on the researches carried out by investigators for tectonic and seismotectonic zoning of Iran, the region subdivided into five structural zones, namely, Alborz-Kopet Dagh zone, Azarbaijan zone, East-Central Iran zone, Makran zone, and Zagros zone. Then, the seismic *b*-value parameter has been computed for these five zones. The results obtained reveal that among these five mentioned zones, the Zagros zone shows the highest *b*-value (1.28), and in contrast, the East-Central Iran zone shows the lowest value (0.84). This finding, more or less, is compatible with the general tectonic nature of the Zagros zone as a fold-and-thrust belt developed by thin-skinned tectonic processes (Moores and Twiss, 1995) and the East-Central Iran as relatively homogenous resistant block (Jackson et al., 1995). According to the results obtained, it can be said that in the Zagros zone the earthquakes with low to moderate magnitudes occur frequently and strong earthquakes occur rarely. In contrast, in the East-Central Iran zone the seismicity pattern is completely different, by occurring large destructive earthquakes but low frequency. In addition, in this research the contour map showing the spatial distribution of *b*-value over the region is presented. This map shows nearly good agreement with the general structural zoning map of the region presented in Fig. 3. According to this map it is concluded that some parts of the Iranian region such as the Central Iran and Eastern Iran clearly show low *b*-values, whereas, some other parts such as the Zagros zone show high *b*-values.

In summary, the results of this research reveal that the study of the frequency-magnitude distribution of earthquakes can be reliably used as a tool to discover the seismic deformation patterns as well as different tectonic structures of the regions. Finally, it must be mentioned that the results of this research same as any other seismicity analysis are significantly related to the accuracy, precision, and the length of the observation period of used data catalogues. So, it is expected that in future by analyzing seismic data recorded by newly installed local seismometers, more reliable results would be obtained.

Acknowledgements

This work was supported by the Research Council of the Damghan University of Basic Sciences. The author would like to thank the anonymous referee and the editor for constructive suggestions that led to significant improvement of the manuscript.

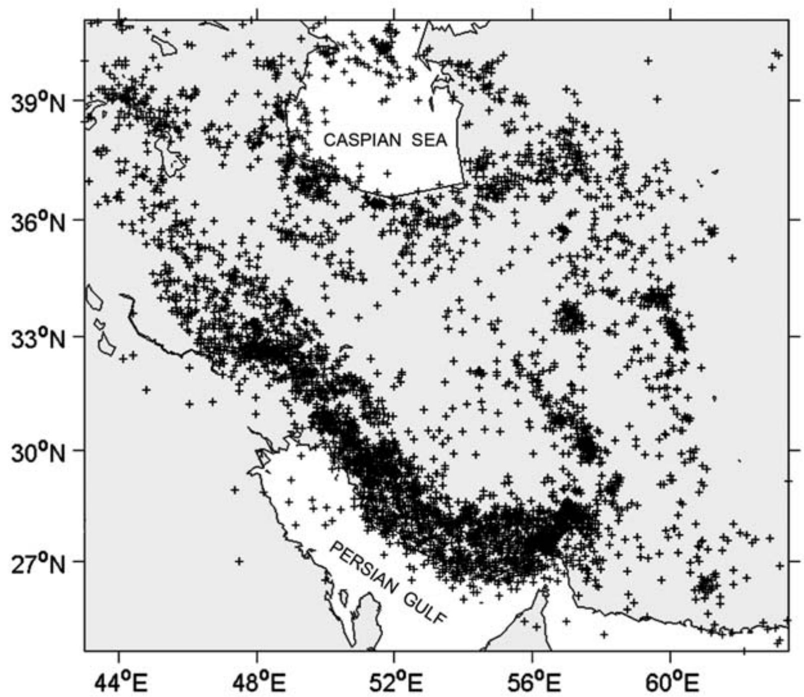

Fig. 1- Map showing the distribution of epicenters of earthquakes in Iran with *mb* 4.0 and greater, occurred during the time period 1957-2007 (events reported by IIEES).

the most investigated equation in seismology, observationally as well as theoretically. It has wide applications, e.g. for estimating the magnitude of future earthquakes, and to perform probabilistic hazard analysis (Turcotte, 1989).

A number of reasons for variations in *b*-value have been suggested. Mogi (1962) pointed to the importance of heterogeneity in contributing to high *b*-value. Scholz (1968) demonstrated an inverse correlation between stress level and *b*-value in laboratory experiments. Mori and Abercrombie (1997) suggested that significant spatial variation of *b*-value occurs in different tectonic environments. Manakou and Tsapanos (2000) supposed that low *b*-values are related to low degree of heterogeneity, large strain rate, large velocity of deformation and therefore large faults.

During the past decades, seismicity patterns have attracted the attention of researchers as a means to investigate the tectonic stress behavior of the regions. On the other hand, recently the significance of the time variation of *b* parameter for quantifying seismicity or for dealing with problems of earthquake prediction has been recognized widely by seismologists (Mandal & Rastogi, 2005; Wiemer & Wyss, 1997; Wiemer & Wyss, 2002). Consequently, it can be said that the study of seismic parameters, especially in the regions with high seismic activity, is very useful for demonstrating the seismotectonic behavior of that regions. So, the main goal of this study is to assess the spatial variation of *b*-value across the Iranian region and to classify it into different tectonic regimes based on this variation.

2. Data analysis and discussion

The earthquake data used in this research are retrieved from the earthquake catalog of International Institute of Earthquake Engineering and Seismology (IIEES). The data used cover a time period of nearly 50 years from 1957 to 2007. The completeness of data catalogue was tested by analyzing the cumulative number of events versus time and selecting a minimum acceptable magnitude of completeness of m_b= 4.0. As presented in Fig. 2, the graph indicating the variation of cumulative number of the events with m_b 4.0 or greater versus time shows nearly a linear trend. This means that m_b 4.0 can be reliably selected as the magnitude of completeness. For the computations performed in this research the ZMAP program (version 6.0) has been used (Wiemer, 2001).

In this study, in order to be able to study the seismic *b*-value variation over the region, the whole region subdivided into structural zones (domains). So, based on the tectonic and seismotectonic zoning maps of the region presented by researchers (e.g., Stöcklin, 1968; Nowroozi, 1976; Berberian, 1976), five structural zones have been defined as follows:

1) Alborz-Kopet Dagh zone
2) Azarbaijan zone
3) East-Central Iran zone
4) Makran zone
5) Zagros zone

These structural zones, bounded mainly by major active faults, are shown in Fig. 3. After defining the structural zones, the earthquake data for each zone were retrieved from data catalogue and analyzed using ZMAP software. Then, *a* and *b* parameters of Gutenberg-Richter relation were computed for zones, using maximum likelihood approach and with a magnitude of completeness (M_c) of 4.0. Fig. 4 clearly shows the diagrams representing the frequency-magnitude distribution of earthquakes in five mentioned structural zones. The values of *a* and *b* parameters computed for each zone are presented in diagrams. Furthermore, in order to be able to compare the *a*- and *b*-values computed for five zones, the bar plots showing these values are shown in Fig. 5. As can be seen in this figure, the highest value of *a* and *b* parameters have been observed in the Zagros structural zone (*a*-value, 8.97 and *b*-value, 1.28). On the contrary, the East-Central Iran zone shows the lowest values of *a* and *b* parameters (*a*-value, 6.25 and *b*-value, 0.84). According to the results obtained, it can be said that in the Zagros zone the earthquakes with magnitudes low to moderate occur frequently and strong earthquakes occur rarely. In contrast, in the East-Central Iran zone the seismicity pattern is completely different, by occurring earthquakes with high magnitudes but low frequency. As mentioned above, estimation of the *b*-value can be used for identifying crustal heterogeneity and the qualitative estimation of stress levels in tectonically active regions (Mogi, 1967; Scholz, 1968; Cao and Gao, 2002; Khan, 2005). So, the results suggest that the Zagros zone shows the highest heterogeneity and lowest stress level whereas the East-Central Iran zone acts as a homogenous resistant block and shows the least heterogeneity.

In this paper, in order to study the spatial variation of the seismic *b*-value over the Iranian region, a net of grid points with one geographic degree spacing in both latitude and longitude was selected. After that, the earthquake data for each grid point and in a circular area with radius of 150 km around the points were extracted from data catalogue. Then, the seismic *b*-value parameters were computed for all grid points using maximum likelihood method. The result is presented as a contour map in Fig. 6. This map clearly depicts the spatial variation of earthquake frequency in the region. As can be seen in this map, the western and southwestern parts of the region (mainly the Zagros zone) show the highest *b*-value contours (shown in the figure with a lighter tone), whereas the remaining parts including the Makran zone, Alborz-Kopet Dagh zone, East-Central Iran zone, and Azarbaijan zone, show low values of b parameter (shown in figure with a darker tone). In addition, the detected NW-SE trend of higher *b*-value contours along the Zagros region and also clearly decreasing trend of *b*-values towards NE and SW is remarkable and completely in agreement with the tectonic setting of the Zagros zone as a typical continent-continent collision zone. Furthermore, a comparison between this contour map and the general structural map of the region (Fig. 3) suggests that high *b*-value contours remarkably correlated

بررسی تغییرات مکانی پارامتر لرزه‌خیزی b در ایران

نوشته: سید ناصر هاشمی*

* دانشگاه علوم زمین، دانشگاه علوم پایه دامغان، دامغان، ایران

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چکیده

در این مقاله تغییرات مکانی پارامتر لرزه‌خیزی b در گستره ایران از رابطه گوتنبرگ- ریشتر مورد مطالعه قرار گرفته است. به این منظور، بر اساس مطالعات به عمل آمده به وسیله محققان پیشین برای پهنه‌بندی زمین‌ساختی و لرزه‌زمین‌ساختی ایران، این گستره فعال و لرزه‌خیز به ۵ پهنه ساختاری اصلی به نام‌های پهنه البرز-کپه داغ، پهنه آذربایجان، پهنه خاور- مرکز ایران، پهنه مکران، و پهنه زاگرس تقسیم شده است. سپس پارامتر لرزه‌خیزی b برای این ۵ پهنه محاسبه شده و مورد تحلیل و تفسیر قرار گرفته است. نتایج به دست آمده نشان می‌دهد که در بین ۵ زون یاد شده، بیشترین مقدار پارامتر لرزه خیزی b به پهنه زاگرس (۱/۲۸) و کم‌ترین مقدار این پارامتر نیز به پهنه خاور- مرکز ایران (۰/۸۴) تعلق دارد. افزون بر این، در این مقاله نقشه پربندی معرف تغییرات پارامتر b در ایران نیز ارائه شده است. با توجه به این نقشه می‌توان چنین گفت که بخش‌هایی از ایران همچون نواحی خاوری و مرکزی ایران نقش بلوک‌های پایدار لرزه‌ای را ایفا می‌کنند. به طور خلاصه می‌توان گفت نتایج این تحقیق گویای این واقعیت است که مطالعه تغییرات مکانی توزیع فراوانی- بزرگی زلزله‌ها می‌تواند در شناخت الگوی لرزه‌خیزی و همچنین ساختار زمین‌ساختی نواحی مختلف بسیار مفید واقع شود.

کلیدواژه‌ها: پارامتر لرزه‌خیزی b، رابطه فراوانی- بزرگی، الگوی لرزه‌خیزی، لرزه‌زمین‌ساخت، ایران.

1. Introduction

Iran is one of the most seismically active regions of the World. This region occupies a part of the Alpine-Himalayan orogenic belt and can be characterized by high topography, recent volcanisms and many active faults that cause the occurrence of destructive earthquakes with different mechanisms. The overall regional seismicity pattern of Iran can be characterized by the continuous activity of moderate-magnitude earthquakes and with less abundance, occurrence of destructive earthquakes with magnitude more than 6. The spatial distribution of earthquake epicentres (m_b 4.0 and greater, derived from IIEES data catalogue) during the recent 50 years period (1957-2007) is shown in Fig. 1. According to this figure, the regional distribution of the seismicity of the Iranian plateau reveals high seismic activity over the whole region, with the concentration of epicentres varying significantly. Higher concentrations occur mainly in the western, south western and northern parts of the region. The remaining parts of the plateau show low to moderate seismicity with a minimum concentration in the Central Iran region. This nonuniform pattern of seismicity of the region may be due to this fact that different parts of the region show different behaviour from the seismotectonic point of view.

The seismicity of Iran was studied by several investigators (Berberian, 1976; Mohajer-Ashjai & Nowroozi, 1978; Niazi & Basford, 1968; Nowroozi, 1971, 1976; Shoja-Taheri & Niazi, 1981). Nowroozi and Ahmadi (1986) calculated the values of *a* and *b* parameters for the 23 seismotectonic provinces presented by Nowroozi (1976). Based on the *a* and *b* parameters computed by Nowroozi (1986), Ahmadi et al. (1989) carried out a probabilistic seismic risk analysis for the 23 mentioned seismotectonic provinces of Iran. Zamani and Asadi (1995) studied the variation of *a*- and *b*- values of seismicity over Iran by analyzing a data catalogue covering 95 years period (1900-1994) and presented the spatial distribution of these parameters as contour maps. Contrary to the study carried out by Zamani and Asadi (1995), in this research a nearly homogenous instrumentally data catalogue covering a 50 years period (1957-2007) has been used for assessing the frequency-magnitude relation of earthquakes in Iran. To this purpose, the variation of the seismic b-value parameter in space, as a criterion for identifying the seismicity pattern, has been studied and the results have been interpreted. This research can be considered as one step in a preliminary study of the assessment of earthquake hazard in the Iranian plateau.

Magnitude of an earthquake is the most commonly used parameter of earthquake size. The statistical distribution of magnitudes for a group of earthquakes is a useful tool for studying the seismicity of regions. Gutenberg and Richter (1954) have provided a simple earthquake reoccurrence or magnitude-frequency relation as:

$$\log N = a - bM \qquad (1)$$

where N is the number of earthquakes in the group having magnitudes larger than M, a and b are constants. a is a measure of seismic activity that depends mainly on the area and the length of the observation period. Statistically, the b-value is the slope on the $logN$ versus M regression line and is a constant parameter that determines the rate of fall in the frequency of events with increasing magnitudes. The estimated b-value varies mostly from 0.7 to 1.3, depending on the tectonics of the region (Barton et al., 1999; Bhattacharya et al., 2002; Kalyoncuoglu, 2007). The b-value represents a statistical measurement of the relative abundance of large and small earthquakes in a group. A higher b-value means that a smaller fraction of the total earthquakes occur at the higher magnitudes, whereas a lower b-value implies a larger fraction occur at higher magnitudes. Frequency-magnitude relation is

magnitude distribution of earthquakes can be reliably used as a tool to discover the seismic deformation patterns as well as different tectonic structures of the regions.

Keywords: *b*-value seismic parameter, Frequency-magnitude relationship, Seismicity pattern, Seismotectonics, Iran.

For Persian Version see pages 181 to 186

E-mail: hashemi@dubs.ac.ir

Key words: Potassic igneous rocks, Adakites, Lamprophyres, Metallogeny of continental arc Porphyry copper deposits.

For Persian Version see pages 161 to 172

E-mail: hatapour@yahoo.com

Distribution and Role of Green Algae in Acid Mine Drainage at Sarcheshmeh Copper Minez

By: S. Orandi*, A. Yaghubpur*, M. Nakhaei*, B. Mehrabi*, H. Sahraei & M. Behrouz****

*Department of Geology, Tarbiat Moallem University, Tehran, Iran.

**Mining and Environment & Water Research Departments, Sarcheshmeh Copper Mine, Kerman, Iran.

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Abstract

Sarcheshmeh Copper Mine, one of the well known porphyry copper deposits, is located in 55 km south of Rafsanjan, south-eastern Iran. Metalliferrous deposit mining, prepare proper conditions for oxidation of sulphide minerals and acid mine drainage will be produced easily by chemical reactions between metal sulphides and water, with the presence of air. Investigations on impact of waste dumps on producing acid mine drainage at Sarcheshmeh copper mine shows decreased pH up to 3-5.5 in acid drainages with the presence of some dissolved toxic and heavy metals higher than permitted standard limits (WHO). In such degraded water and improper environment for aquatic life, just some of microorganisms are able to survive. At Sarcheshmeh copper mine in some of acidic drainages which maintain high dissolved elements, an acid tolerant alga recognized. The genus of this filamentous green alga is *Ulothrix* and species is *Ulothrix gigas* without antimicrobial and antifungal properties. The alga is observed in the drainages with high dissolved solids (TDS≈1800mg/l). It seems pH values, type of dissolved elements and secondary minerals formed on the substrate, are important factors in distribution of *Ulothrix*. This research shows the most prolific and densely populated communities occur in effluent with the pH 3- 4.5. The colloidal conditions and presence of suspended Iron and Aluminium prevent growth or reproduction of them. Sampling and chemical analysis of algae show elevated absorption of heavy metals. Therefore the presence of this alga is a factor to remove heavy metals from acid mine drainage naturally and improve the water quality.

Keywords: Acid mine drainage, Filamentous green algae, Ulothrix *gigas*, Sarcheshmeh copper mine

For Persian Version see pages 173 to 180

E-mail: orand_san@yahoo.com

An Assessment of the Spatial Variation of the Seismic *b*-Value across Iran

By: N. Hashemi*

* Damghan University of Basic Sciences, Damghan, Iran

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Abstract

This paper presents a study of the spatial variation of Gutenberg-Richter seismic *b*-value over the Iranian region. For this purpose, based on the works carried out by investigators for tectonic and seismotectonic zoning of Iran, the region subdivided into five structural zones, namely, Alborz-Kopet Dagh zone, Azarbaijan zone, East-Central Iran zone, Makran zone, and Zagros zone. Then, the seismic *b*-value parameter has been computed for these five zones. The results obtained reveal that among these five mentioned zones, the Zagros zone shows the highest *b*-value (1.28 ± 0.03), and in contrast, the East-Central Iran zone shows the lowest value (0.84 ± 0.08). In addition, the contour map showing the spatial distribution of *b*-value over the region is presented. According to this map, some parts of the Iranian region such as the Central Iran and the Eastern Iran clearly act as resistant (rigid) blocks. In summary, the results of this research reveal that the study of the frequency-magnitude distribution of earthquakes can be reliably used as a tool to discover the seismic deformation patterns as well as different tectonic structures of the regions.

Keywords: *b*-value seismic parameter, Frequency-magnitude relationship, Seismicity pattern, Seismotectonics, Iran.

For Persian Version see pages 181 to 186

E-mail: hashemi@dubs.ac.ir